Earth Surface Processes and Landforms
Earth Surf. Process. Landforms **25**, 463–481 (2000)

CONDITIONS OF FORMATION OF STRATIFIED SCREES, SLIMS RIVER VALLEY, YUKON TERRITORY: A POSSIBLE ANALOGUE WITH SOME DEPOSITS FROM BELGIUM

STUART A. HARRIS[1]* AND ANGÉLIQUE PRICK[2]
[1]*Department of Geography, University of Calgary, Calgary, Alberta, Canada T2N 1N4*
[2]*Belgian National Foundation for Scientific Research, Université de Liège, Département de Géographie Physique et Quaternaire, Sart Tilman, B.11 Liège, Belgium*

Received 4 March 1999; Revised 6 September 1999; Accepted 12 October 1999

ABSTRACT

Stratified scree is forming today on 34–45° north-facing slopes in gullies in the Kluane Lake area of the St. Elias Range of the Yukon Territory. Low winter snowfall leaves the slopes snow-free in the dry spring weather, so that dry grain flows are extremely active. The coarsest material moves to the bottom of the slope, while the finer material is left behind. Summer rains mobilize the matrix-rich material upslope and cause it to flow down and cover the clast-supported deposits from the dry grain flows. The matrix-supported debris flow material dries and hardens, stabilizing the clast-supported material. This occurs in a region of discontinuous permafrost, but permafrost is not involved in the processes.

A remarkably similar Pleistocene deposit occurs at Noiseux in Belgium. Detailed examination of the deposits from the Yukon and Noiseux shows that they have essentially similar characteristics, suggesting that the main deposit at Noiseux formed in the same way from frost-shattered Famenne siltstone with small quantities of loess. The deposit remaining today represents the sediments at the toe of this scree. Thus climatic conditions at Noiseux during part of the Late Pleistocene were similar to those found today at Kluane Lake. Copyright © 2000 John Wiley & Sons, Ltd.

KEY WORDS: *éboulis stratifié*; stratified scree; Late Pleistocene climate; dry grain flows; debris flows

INTRODUCTION

The formation of stratified slope deposits related to cold climatic conditions (both present-day and Pleistocene) has been discussed for about half a century. Unfortunately the early work was marred by a lack of detailed description of present-day analogues (e.g. Malaurie, 1949; Guillien, 1951; Corbel, 1954; Journaux, 1976) so that the justification for the explanations and theories of formation was not without problems. This situation has improved in the last 15 years, and there are now good literature reviews dealing with the modern theories based on careful studies (e.g. Bertran *et al.*, 1992; van Steijn *et al.*,1995).

Stratified screes (*éboulis stratifié* or *éboulis ordonné* in French) have been defined as slope deposits presenting alternating openwork and matrix-rich layers (Tricart and Cailleux, 1967). Some confusion arises in the literature between the stratified screes and the *grèzes litées*; however, the latter are not scree deposits. *Grèzes litées* lie on the lowest part of the slopes, i.e. less steep slopes (<30°; Heine, 1995). The material is usually finer (sand, gravel size), better sorted and characterized by a finer bedding than that of the deposits caused by gravity (Francou, 1988). Unfortunately a very wide variety of Pleistocene deposits have been included in the term *grèzes litées*, and it is now recommended that this term be restricted to the deposits at the original location in Charentes (French *et al.*, 1995).

Numerous theories have been suggested for the origin of true stratified screes, ranging from the role of flowing water (Guillien, 1951), and the combined action of congelifluction and flowing water (Journaux,

* Correspondence to: Prof. S. A. Harris, Department of Geography, University of Calgary, Calgary, Alberta, Canada T2N 1N4. E-mail: harriss@acs.ucalgary.ca
Contract/grant sponsor: NSERC; contract/grant number: A-7483
Contract/grant sponsor: FNRS; Northern Scientific Training Grants

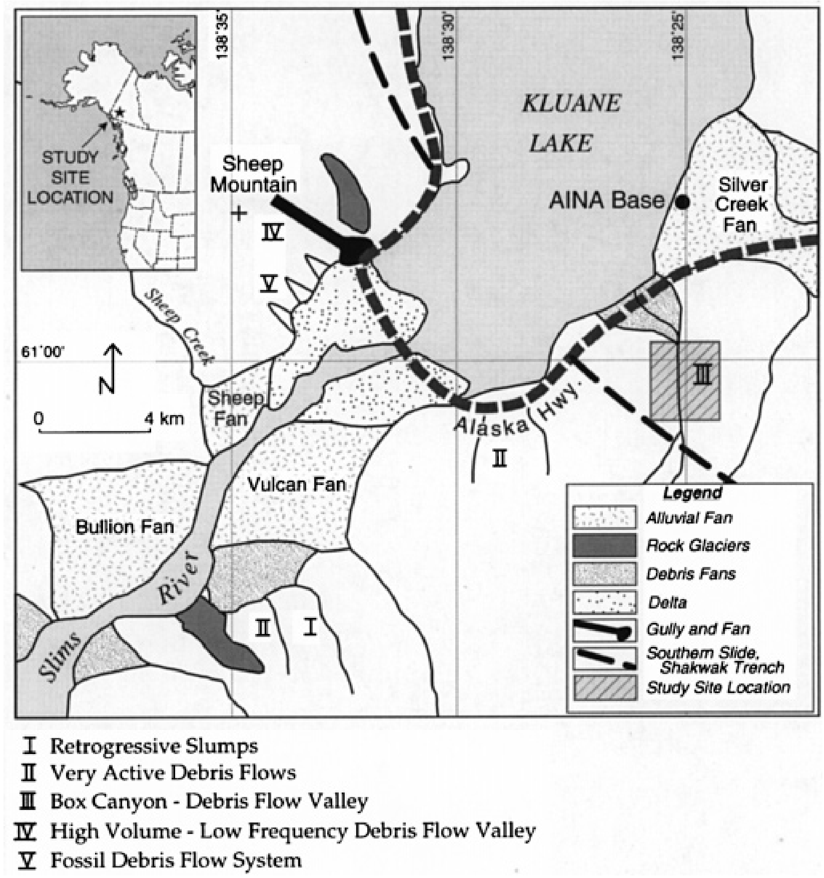


Figure 1. Location of the study area in the Slims River Valley, southwestern Yukon Territory. The roman numerals show the stage classification of the debris flow valleys according to Harris and McDermid (1998)

1976), to a decisive role of frost comminution, combined with other processes such as needle-ice sorting, frost creep, gelifluction, frost sorting, grain flows, flowing water and rock falls. The most comprehensive model suggested so far is the stone-banked lobe model of Francou (1988, 1990), which can operate on slopes from 35° down to <10°. Many theories involve a nivational environment in some form (e.g. Guillien, 1964; Hétu *et al.*,1995), although Harris (1975) working in New Zealand and Wasson (1979) working in the Hindu Kush found no evidence to support this in those locations.

Another sensitive area is the significance of each cyclothem. Van Steijn *et al.*(1984) assume that each cyclothem represents seasonal elements so that each corresponds to a single year, but Lliboutry (1961) had earlier suggested that they were episodic, each event being separated by a gap of several years. The stone-banked lobe model also follows the latter idea since it involves slow, downslope movements of a thin (<20 cm thick) layer of a few centimetres per year.

The present study has evolved from a request by Professor A. Pissart to the senior author to look for modern analogues for the deposits described from Belgium. A possible analogue was encountered near Kluane Lake, Yukon Territory (Harris and Gustafson, 1988), and it appeared sufficiently similar to the limited descriptions of the Belgian deposits that more study might be warranted. In 1997, Professor Pissart and the authors visited the Kluane site and confirmed that this was so. Accordingly, Professor Harris is carrying out more detailed studies on the Kluane stratified screes while Dr Prick has re-examined the two limited, available outcrops of the Famennian screes. This paper presents a preliminary report on this work.

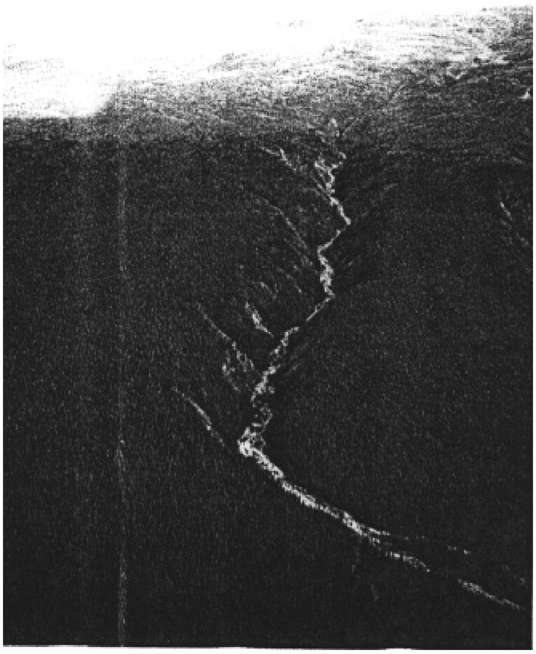


Figure 2. Aerial view of the box-canyon cut into the northern slope of Outpost Mountain

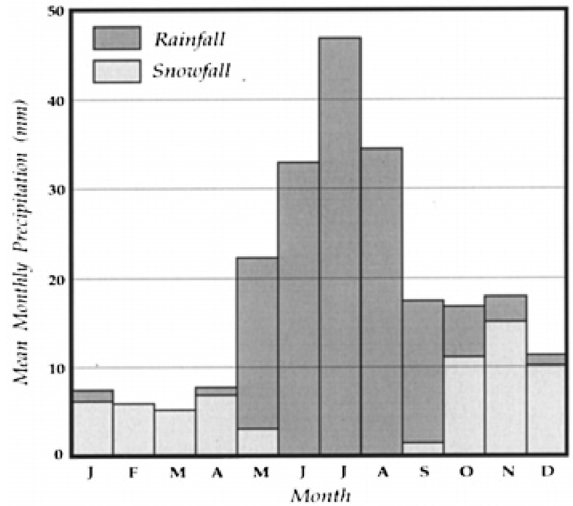
KLUANE LAKE STUDY AREA

Figure 1 shows the location of the box-canyon debris flow valley in southwest Yukon Territory where the stratified slope deposits are forming (Harris and Gustafson, 1988, photo 5). The research site is located 80 km west of Haines Junction and at an elevation ranging between 1100 and 1250 m a.s.l. The valley represents the intermediate stage III in the evolution of retrogressive debris flow valleys towards fluvial valleys (Harris and McDermid, 1998). Former studies by the senior author showed that debris flow activity is the main erosive agent in this canyon, although other agents such as river action also generate some erosion. Frequency of debris flows in the valley is about once in 50 years, so stratified slope deposits can develop at the base of the steep canyon walls where conditions are suitable.

The box-canyon debris flow valley is eroded in a melange of Palaeozoic slates, greywackes, limestone, dolomite, conglomerates, serpentinite and greenstone on the south side of the Shakwak trench (Wheeler, 1963; Clague, 1979). Since the site lies within 1 km of the Denali Fault and is close to the Duke River Fault, the rocks show considerable shattering, and are also the locus of numerous compensatory faults. Total lateral movement along the Denali Fault is estimated at 360 km since the middle of the Tertiary period (Kay and Colbert, 1965, p. 531). Overlying the bedrock is a thin deposit of till.

The box-canyon forms a deep north–south valley cut into the slopes of Outpost Mountain (Figure 2); its dimensions are given inHarris and Gustafson (1988, figure 4). Valley walls have slopes between 34° and 85°, and the stratified slope deposits are developing on the east-facing valley walls where they are about 70 m high.

The climate is continental with cold winters and warm summers (Figure 3). The mean annual air temperature at the AINA Kluane Base (at 781 m a. s. l.) is $-2{\cdot}7$°C (Environment Canada, 1982), but the study site is higher and colder. Precipitation (468 mm a^{-1}) is primarily as rain in early summer (late May–July) and



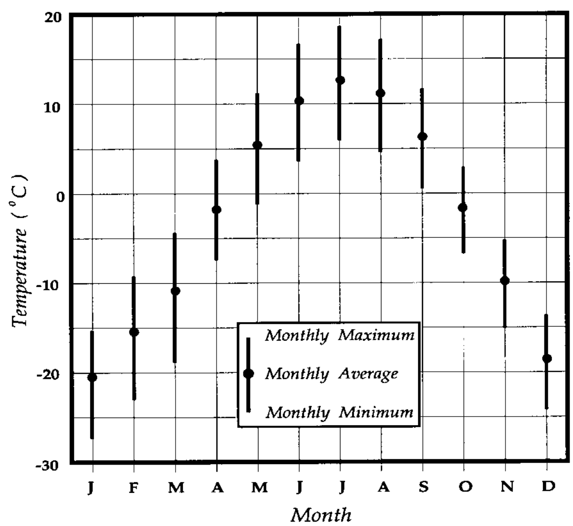


Figure 3. Climate at the Kluane Lake Base of the Arctic Institute of North America (Environment Canada, 1982)

as limited snowfalls occurring in fall or early winter. Maximum snow depths on the valley floor are about 50 cm, but these are decreased by periodic Chinooks (foehn events) and sublimation as the weather improves in late winter. Avalanches remove the snow from the valley walls so that the rocks are subjected to freeze–thaw conditions without a protective snow cover from March to May.

This slope of Outpost Mountain exhibits continuous permafrost, and is covered in white spruce, aspen and balsam poplar with an understorey of willows and alders. The slopes where the stratified scree is forming lack vegetation (Figure 4).

Figure 4. The unvegetated slopes above stratified scree site F. The valley wall is about 70 m high with slopes ranging from 34–45° on the scree deposit, 55° in the middle to 70–85° on the upper slopes

METHODS USED

The section of the box-canyon floor with the active stratified screes in the Yukon was mapped to determine its location. Straight lines were painted across the screes and the ends marked on reinforcing bars or rock outcrops. These were usually revisited at short intervals (e.g. 6–10 days from early May to mid-July in 1998) and the changes were noted. New lines in different colours were used to replace lines that had disappeared. In 1998, collecting trays about 40 cm in width were fixed to the surface of the fan to measure rates of accumulation (Figure 5).

Squares of 40 cm and 60 cm were painted on the main source rocks on slopes facing south, north and east, the colour of the paint being selected to provide a similar albedo to the rock. These were re-examined every 6–10 days.

Samples of the sediments on the stratified scree were collected, as was a sample of the shattered bedrock that acted as the source of the sediment. Slope angles and directions were measured as well as the dimensions and directions of the long axes of 50 stones on three screes. In Calgary, the samples were sieved to determine the grain size distribution. The lithology of 329 pebbles coarser than 4 mm was determined, together with their shape, using the Krumbein (1941) method. Grain size of the fine fraction of the samples was determined using the pipette method, with hydrogen peroxide pretreatment and using calgon as the dispersing agent (Folk, 1980). Atterberg limits were also determined on the samples.

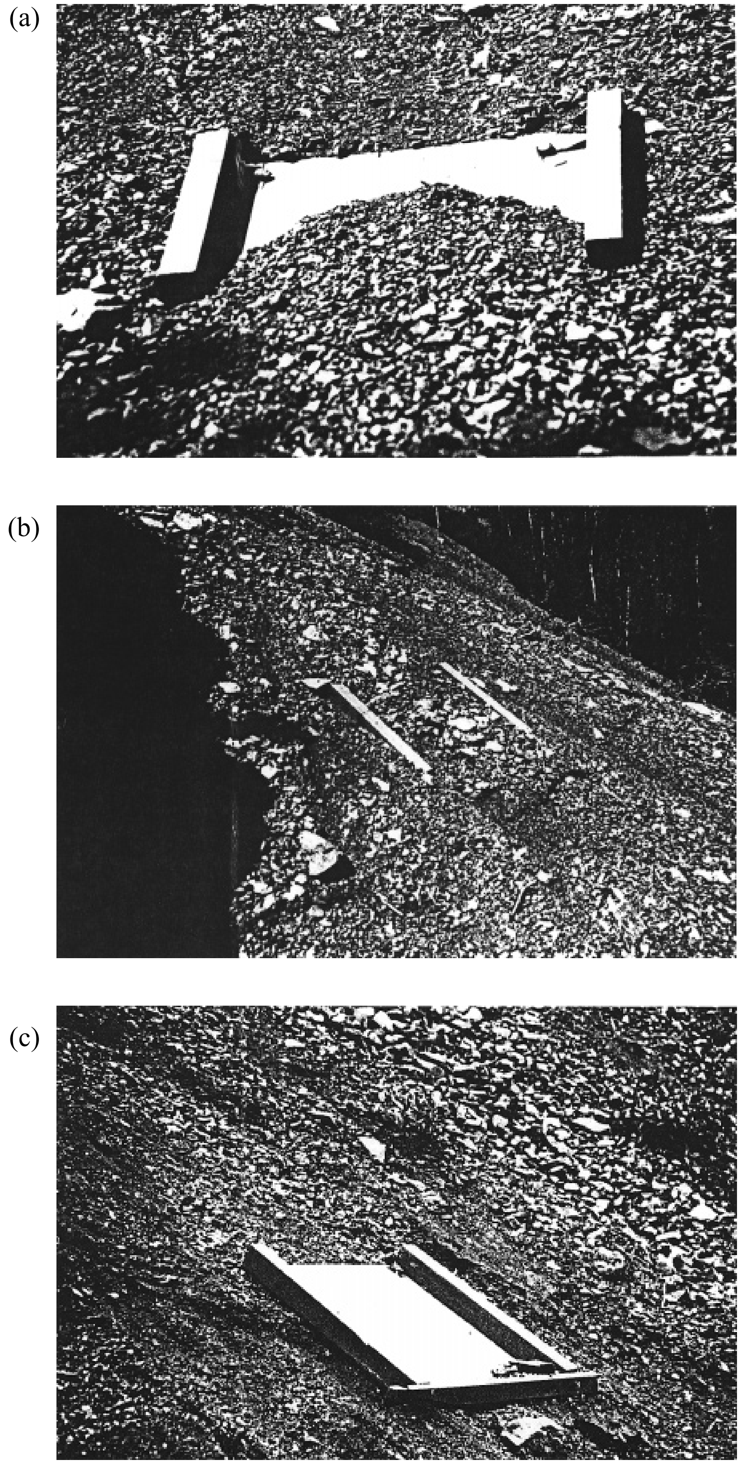


Figure 5. Collecting trays on the stratified scree: (a) after emplacement; (b) after 10 days, showing partial burial; (c) with a baffle to collect the moving sediment

RESULTS

Field teams have visited the site in most years since 1987. The same sequence of events is seen each year, i.e. dry grain flows in spring, followed by small debris flows after the high rainfalls in summer. In July 1988, heavy rains for three days resulted in a major debris flow down the valley which removed much of the accumulated stratified scree, but the latter has been rebuilt with successive cyclothems in the same places. Six gullies (A–F) currently produce stratified scree deposits (Figure 6). All are on east-facing slopes where the walls of the box-canyon are highest, and the fragile bedrock outcrop rapidly produces suitable material in May and early June. Minor damage to the stratified screes can occur due to movement of the stream on the valley floor, resulting in undercutting of the slope, and by sediment building out over melting snow from avalanches.

Slopes. All the scree slopes had a slope exceeding 33°. In the case of slope F (Figure 4), the upper 3 m in till was vertical, while the next 22 m down consisted of slopes ranging from 70° (gully floor) to 85° (rock walls). Below this, the gradient of the gully decreased to 55° while the concave surface of the fan had a slope of 45° at its apex, decreasing to 34° at its base. The gully wall was about 70 m high, and the actively descending sediments form a fan, building out over the bedrock.

Types of movement. In May and early June, the surface of the stratified scree was covered in dry, loose rock fragments (Figure 7) which are clast-supported. The individual fragments moved at the slightest provocation, e.g. sometimes due to drying in the sun and sometimes due to wind. Collapse and movement in the form of small lobes or masses was common, as described by Hétu *et al.* (1995, p. 181). Lines painted on the fragments would largely disappear in six days, as did other coloured lines added subsequently. The painted stones were found scattered over the slope beneath the original line up to 4 m below it, and showed a random rotation. The material was dry; hence the name ‘dry grain flow’ was used for this movement.

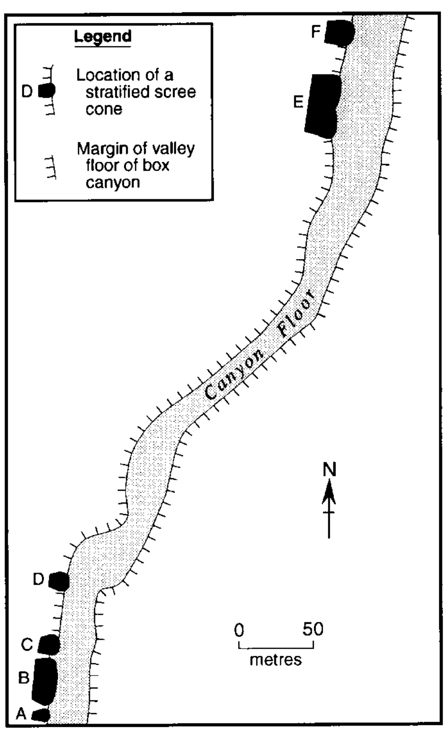


Figure 6. Location of the active stratified scree slopes along the north–south trending debris flow valley, Kluane Lake

Figure 7. Clast-supported fragments making up the dry grain flow deposit on slope F

When collecting trays were placed on the slope, those in the most active sites became almost buried in about 10 days (Figure 5). By putting a baffle on the lower side of the others, the moving sediment could be readily collected and sampled in the following six days.

The 40 cm $\times$ 40 cm painted squares on the serpentinite bedrock showed contrasting results. The sound rock on the north-facing slope showed no change after 10 days, while that on sound rock on the south-facing slope lost about 3 percent of its surface. In contrast, the square on the shattered serpentinite bedrock of the gully floor could scarcely be recognized; about 70 percent was lost from the rock. Examination of the actual scree material moving down the upper 25 m of the gully suggested that the finer material tended to stop its motion before the coarser grained material. There was a clear increase in grain size with distance down both the gully and the fan.

When the rains came in summer, fresh thin debris flows appeared on top of the dry grain flows. The coarser material in the latter was apparently stable, but fine grained, matrix-supported material flowed down the slope from the upper parts of the gully. The debris flows were sometimes seen in motion. They covered the dry

Figure 8. Debris flow deposits descending over the surface of the dry grain flow

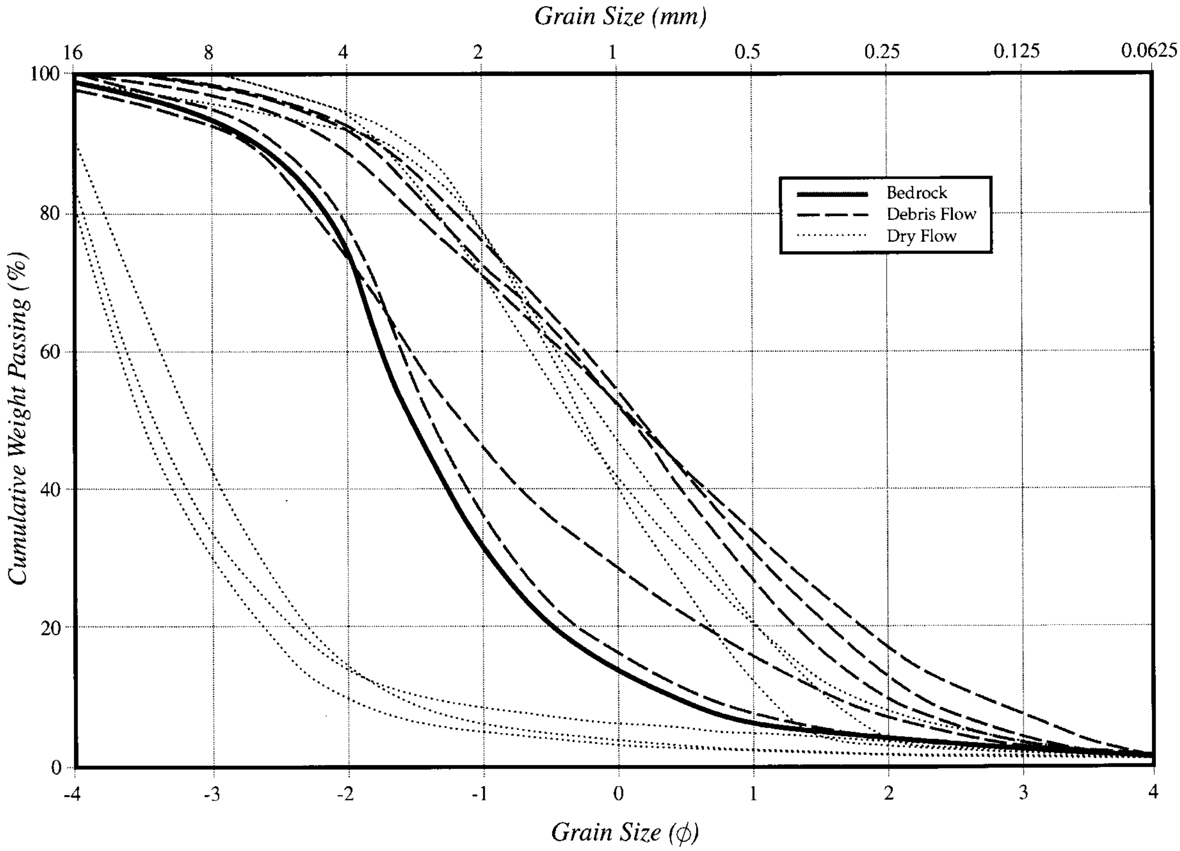


Figure 9. Grain size analysis of bedrock, debris flow deposits and dry grain flows by sieving

Table I. Pebble lithology (>4 mm fraction) and pebble shape (Krumbein, 1941) for a sample of dry grain flow deposit

Lithology	Percentage	Mean shape
Calcareous mudstone	55·5	0·25
Greenstone–serpentinite	22·4	0·24
Dolomitic mudstone	6·6	0·24
Limestone	4·9	0·23
Shale	4·6	0·35
Marble	3·3	0·24
Other	2·7	0·23

grain flow material, including the painted lines (Figure 8), apparently without disturbing the underlying deposit. In the course of the summer, the entire fan becomes covered in this way. When dry, the layer of debris flow material forms a harder, stable layer, preventing the underlying clast-supported material from moving further downslope, even though this is at 34–45°.

When seen in cross-section, these two types of material are found to make up the cyclothem. The number of layers formed since 1988 is consistent with each cyclothem representing a single year of deposition.

Parent materials. Table I shows the lithologies of the fraction >4 mm diameter in a typical sample of dry grain flow, together with the mean shape for each lithology (Krumbein, 1941). The two dominant lithologies are greenstone–serpentinite with hornblende or chlorite, and calcareous mudstone with calcite veins. This reflects the lithologies found in the bedrock of the canyon walls. Each location of the stratified scree occurs

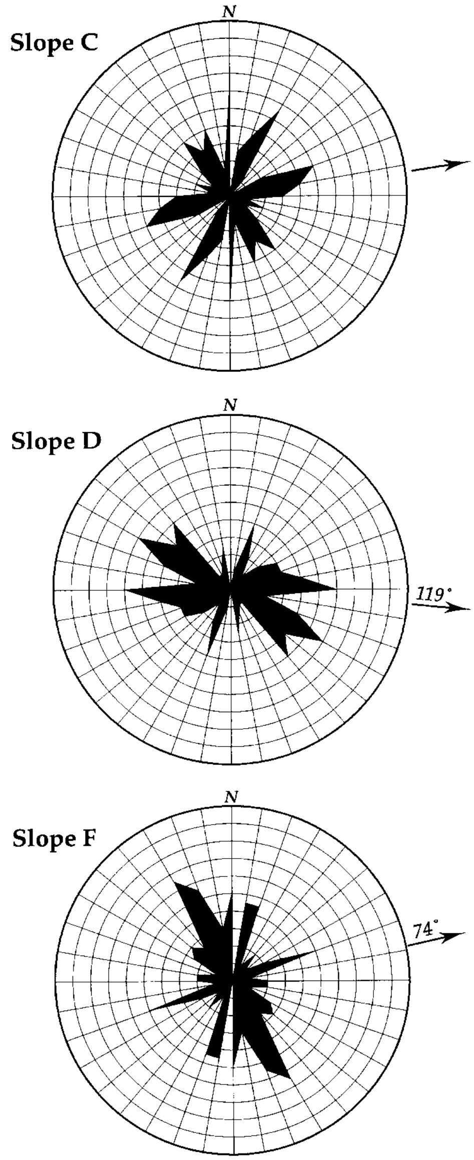


Figure 10. Rose diagrams for the stones in dry grain flows on scree slopes C, D and F. The outer circumference corresponds to 12 pebbles in the class

below a gully forming in rock which is exceptionally shattered by jointing, cleavage or faulting. The fracturing of the serpentinite makes it appear like a fractured shale along the fault lines. Mean shape of the pebbles was 0·25, indicating a subangular shape. This compares with 0·17–0·18 as the mean shape of hard greywacke fragments in the stratified screes of New Zealand (Harris, 1975). In the latter case, the source slopes were only 5–10 m in length, compared with 70 m at Kluane.

Grain size analysis. Figure 9 shows the results of grain size measured by sieve analysis. It includes one sample excavated from shattered bedrock, and six samples each from the dry grain flows and the debris flow layers. The samples of bedrock and dry grain flows exhibit essentially similar grain size distributions. The variations in mean grain size are due to variations in the size of the fragments in the shattered bedrock, and

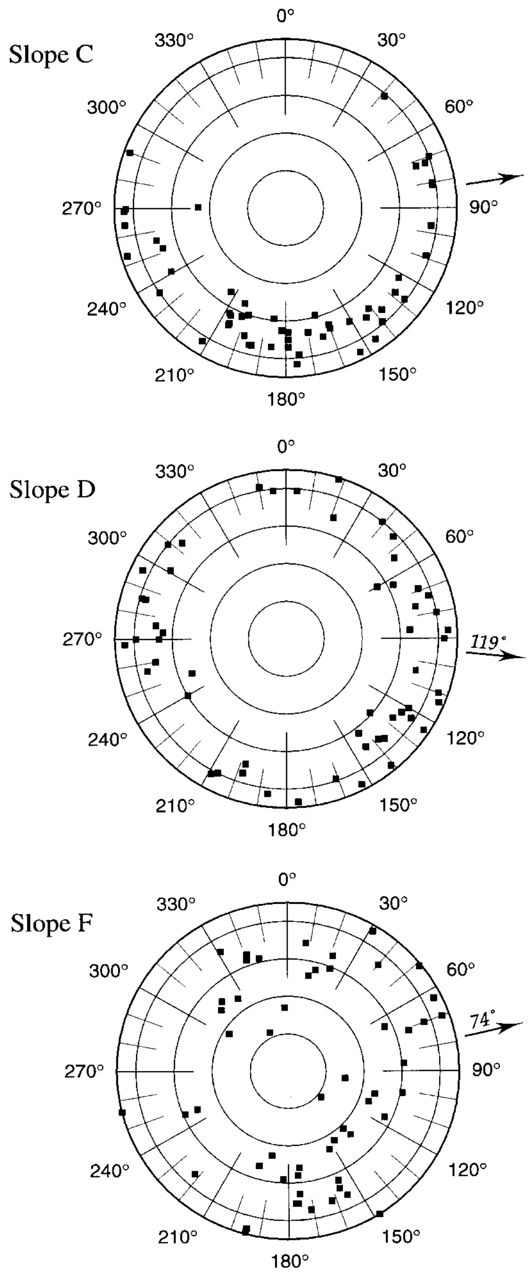


Figure 11. Stereographic projections of the 'a' axes of the stones on scree slopes C, D and F

this is obvious when comparing the dry grain flow material to that in the parent bedrock. The debris flow layers show sorting and a greater proportion of fines. Mean grain size of these samples was always smaller than that of the bedrock sample. When the grain size distributions are plotted on logarithmic probability paper, there is no evidence of mixing of materials.

Grain size measurements by the pipette method confirmed the higher content of fines in the debris flow samples (13 per cent clay) as opposed to the dry grain flows (8 per cent clay), but also suggested that some of the coarser particles (>2 mm) may break down into finer material when wetted.

Atterberg limits. The materials were non-plastic, i.e. they change directly from the solid to the liquid state with the addition of water. The liquid limit ranged from 10 per cent to 18 per cent, but was not obviously related to the mean grain size of the material by sieve analysis.

Mineralogy. The calcareous mudstone consisted of montmorillonite, kaolinite and chlorite with minor amounts of illite; however, the greenstone–serpentinite contained kaolinite, chlorite and illite but lacked montmorillonite. Accordingly, the composition of the clays in the stratified scree varied with the relative proportions of these parent materials. Thus, below greenstone–serpentinite cliffs such as at site F, montmorillonite is almost absent. It is important to stress here that the presence of swelling clays has been shown to be an active agent in weathering by wetting and drying (Hames *et al.*,1987; Delgado-Rodrigues,1988).

Pebble orientation. Rose diagrams (Figure 10) for stones in dry grain flows on three of the fans (C, D and F) show either a dominant mode downslope (slope D) or a dominant mode across the slope. When the rock fragments are in motion, they often move as a lobe which moves in a fanshaped from, which would explain the breadth of the dominant modes.

When the long axes (a) of some pebbles are plotted on a stereographic projection (Figure 11), they either form a girdle (slopes C and D) or are random (slope F). Once again, degree of scatter is very high in all cases.

DISCUSSION

The stratified scree material originates in shattered or fissile rock in the spring. Rock lithology is not critical, but the degree of shattering of this rock controls the size of the particles and rock fragments which are produced. The resulting material forms screes below steep cliffs facing east on slopes ranging from 34° to 85°.

The downslope movement in the spring takes the form of dry grain flows. Both individual grains and small masses may move, but the coarser material moves further than the finer material. This produces a layer of clast-supported material on the surface of the fan at the base of the gully. The finer material upslope descends as small debris flows after rains to cover the clast-supported material as a thin layer of matrix-supported sediment. Once it covers the granular sediments resulting from the dry grain flows, movement of the clast-supported material ceases in spite of the steep slope.

Necessary climatic conditions include low winter snowfall so that the slopes are snow-free in the spring. Spring must also have minimal rainfall, to be followed by a rainy summer to produce the debris flows. Winter snows tend to be removed from the slopes by wind and avalanches.

Exact limiting topographic conditions are uncertain since too few examples have been seen so far. There may be a trade-off between slope and material availability so that where suitable sediment is available, the stratified screes can form on shorter and less steep slopes. Segregation by grain size is essential.

The preservation of the cyclothems depends on several factors. In this case, the main damage is done when a major debris flow occurs along the main box-canyon, removing up to 3 m of sediment from the floor, as well as the lower part of the stratified scree as in 1998. The stream flowing on the floor of the box-canyon can change position during times of snowmelt and can undercut the fan. Finally, snow from avalanches piles up at the base of the slope and the new layers of sediment may be built over the snow. When the latter melts, part of the fan can collapse and disconformities can be produced in sediments at the base of the fan.

This represents a distinctly new model from the stone-banked lobe model described from the high Andes of Ecuador and Bolivia by Francou (1988, 1990). In the Yukon model, the layers consist of alternating dry grain flows and thin debris flows.Hétu *et al.* (1995)have experimented with artificial dry grain flows on short, steep slopes and reported that the finest material descended through the clast-supported layer and lodged at its base. No evidence was seen for this happening at Kluane, and fines were collected with the coarse material from the sediment traps (see Figure 11). However, the present results support their conclusion that dry grain flows may be involved in the formation of stratified scree at higher latitudes or with cold climates. At Kluane, the coarsest material always travels furthest, leaving the finer material behind to form a suitable source for the debris flows which occur during the summer rains. This is consistent with the description of van Steijn *et al.* (1995). The high variability in the pebble orientation in the clast-supported beds at Kluane agrees with the

experiences of Hétu *et al.* (1995, p. 180) in their artificial experiments. No well-developed inverse grading of the type described by van Steijn *et al.* (1995, p. 128) was encountered at Kluane.

Hétu *et al.* (1995, p. 174) concluded that no palaeoclimatic significance can be inferred from the occurrence of dry grain flows on their own, but it has taken about 30 years of searching to find the Kluane stratified scree. The combination of the clast-supported dry grain flow and thin matrix-supported debris flowing on slopes steeper than 34° has only been found in this specific climatic zone in the North American Cordillera, so it seems reasonable to infer that this combination of cyclothems is only developed under these local, specific climatic conditions.

FAMENNE STUDY AREA

Belgium developed permafrost during the cold events of the Pleistocene. In its southern part, the mean annual temperature at some stage dropped more than 13°C, reaching a value lower than −5°C. Rock types responded differently to the colder continental climate during glaciations (Pissart, 1995), the deep, repetitive freezing causing a rapid and widespread mechanical disintegration of rocks. As a result, the siltstones tend to occur in depressions surrounded by limestone and quartzite uplands. On the slopes, mass movements were accelerated by the lack of vegetation and by possible seasonal saturation of the active layer (Pissart, 1995). In the Famenne, the siltstone fragments were easily moved by flowing water so that regosols with under 20 cm of shattered rock overlying bedrock are common. Downslope, stratified material and evidence of water action are found in stratified sediments similar to the *grèzes litées* of France, for example, at Wanlin (Macar and Alexandre, 1958; Alexandre & Macar, 1960; Seret, 1963). These sediments also contain more silt and clay than in typical *éboulis stratifié*. Up to now, these deposits could not be dated. This transport by water would explain the slight rounding of the siltstone fragments. Transport speed was probably quite slow, but much higher than what is observed today in temperate conditions (Pissart, 1995).

Loess was deposited during the glaciations in northern Belgium, but is less obvious in the south. Almost all the slope deposits of southern Belgium were formed under periglacial conditions. They usually consist of shattered fragments mixed with loess (Pissart, 1995). The periglacial slope deposits of southern Belgium are most often described as small rock fragments (a few millimetres long), generally slightly rounded, arranged in alternating openwork layers and layers with a loess matrix. Siltstone fragments are emplaced with their longer axes oriented parallel to the slope. On steep slopes, the inclination of the cyclothems can reach 28°, i.e. a value as high as the one due only to gravity (Pissart, 1995).

At Noiseux, an *éboulis* was developed at the base of the cliff on the floodplain of the River Ourthe at 50°18·424′N, 5°23·173′E, 34 km east of Dinant and 40 km southwest of Liège (Figure 12). These deposits were briefly described by Juvigné (1963)and by Seret and de Béthune (1967).

METHODS USED

In Belgium, the exposures in the stratified slope deposits described during the last half century have been largely destroyed. Drs Prick and Pissart visited some sites in 1997 and Dr Prick described and sampled the materials exposed at Noiseux at that time. The samples were brought back to Calgary and subjected to the same analyses as the Yukon materials. Only the Noiseux deposit will be described here, as it is the one showing similarities to the Yukon material.

RESULTS

The sections occur in the bank of a road cut into the base of the eastern cliff in Famennian siltstones along the upper margin of the floodplain of the River Ourthe at 160 m a.s.1. (Figure 12). This rock can be described as an unmetamorphosed fossiliferous (brachiopod-bearing) friable siltstone. The siltstone fragments have been largely exploited by the local people for grit-size material and only two outcrops, each a few metres long, could be examined in 1997. The section described and sampled was the southernmost one, but the other one appeared to be in identical materials.

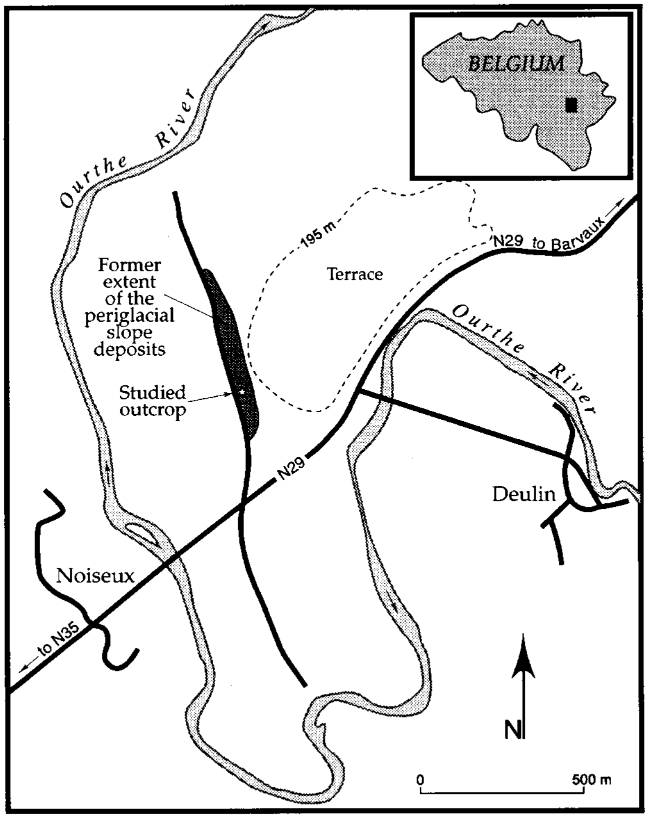


Figure 12. Location of the study area in Noiseux, Belgium

The deposit consists of alternating beds of clast-supported siltstone fragments and matrix-supported sediment, 4 to 20 cm thick (Figure 13). The layering is not regular, but is disturbed by local deposition of matrix-rich material in lenses (Figure 14).Seret and de Béthune (1967)ascribe this to a locally concentrated flow of sediment.

Slopes. The slope of the bedding of the deposit ranges from 16° to 21°, i.e. less than the values measured in Noiseux on outcrops that have now disappeared: 26° (Pissart, 1976) and 35° (Seret and de Béthune,1967). It is reasonable to conclude that there was quite a variety in the dips of these deposits along this valley side. Macar and Alexandre (1958) also reported thinner beds than those preserved today.

The deposit extended upslope for about 8 m, but was probably no more than 2–3 m thick. The slope above the deposit is short and culminates only about 35 m higher, on a river terrace lying at 195 m a.s.1.

Grain size analysis. Figure 15 shows the grain size of two typical samples, one from a clast-supported layer and one from the matrix-supported sediment. These two samples have an essentially similar grain size, but the mean grain size of the matrix-supported sediment is smaller than that from the clast-supported layer. The matrix-supported sediment shows noticeably poorer sorting, as in the case of the matrix-supported sediment in the Yukon example.

The finer fraction of the matrix-rich layer appears to include loess coming from the upper part of the slope, since the mean grain size of the loess deposited in Belgium is around 50 μm (Pissart, 1995). When the grain size distributions are plotted on logarithmic probability paper (Doeglas, 1946), the distribution of the matrix-supported material suggests that it is a mixture of 90 per cent shattered siltstone mixed with 10 per cent loess. The clast-supported material contains about 95 per cent of shattered siltstone.

Figure 13. View of the outcropping deposit in Noiseux. Layers of clast-supported and matrix-supported material are alternating. Some of the clast-supported layers can be several decimetres thick

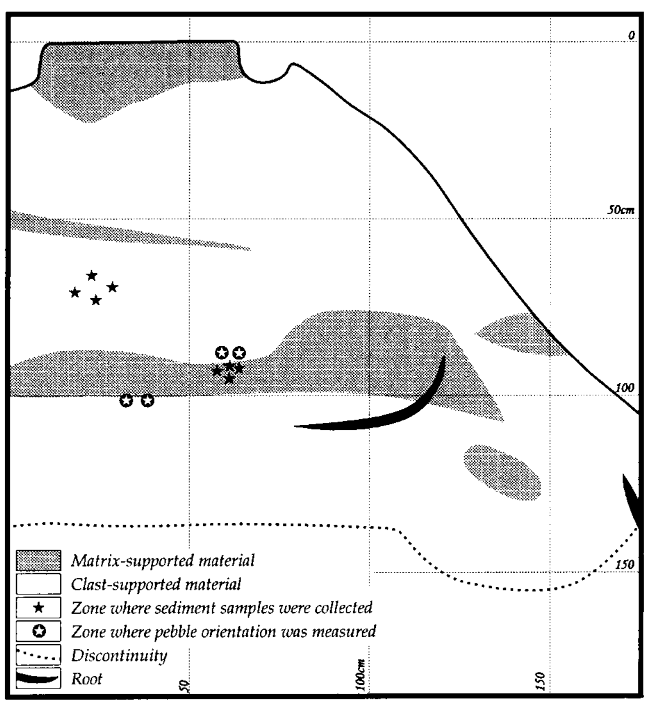


Figure 14. Distribution of clast-supported and matrix-supported layers in the Noiseux deposit

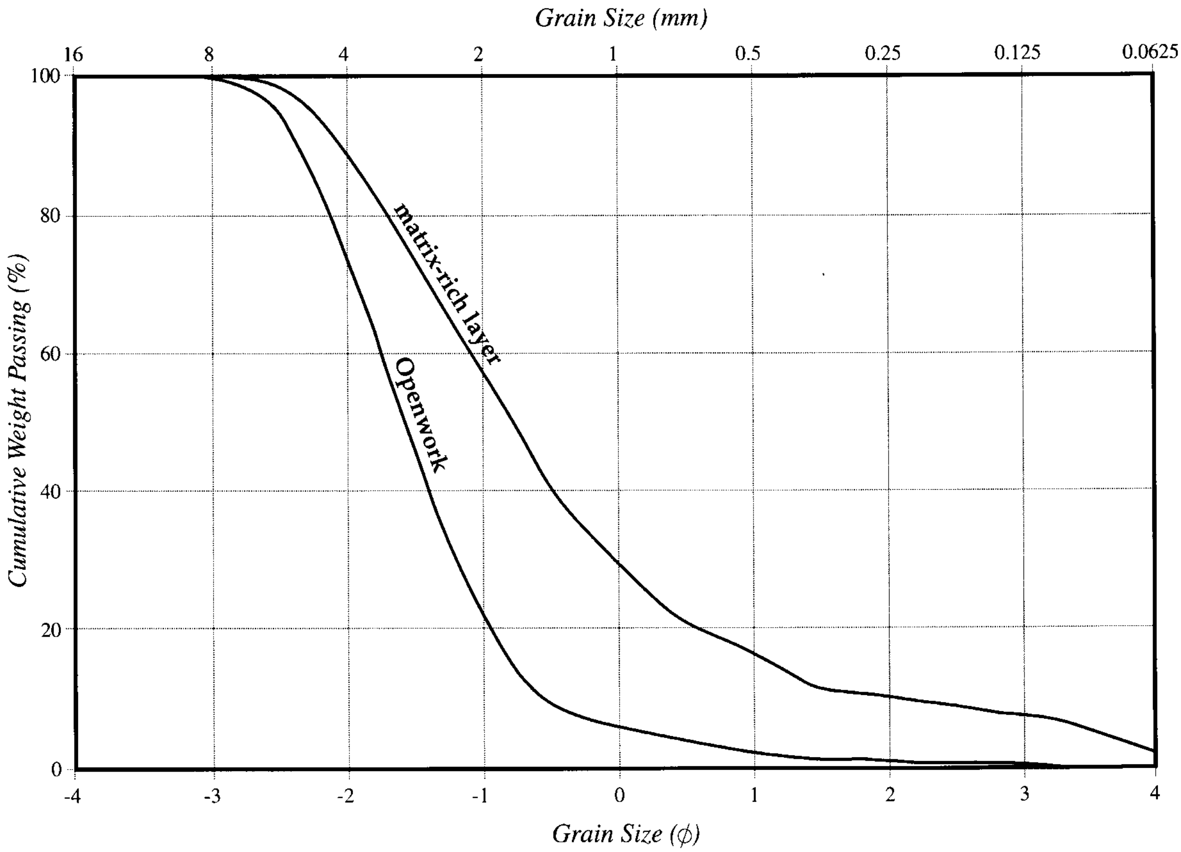


Figure 15. Grain size analysis of the Noiseux deposit

Lithology, roundness and elongation. The rock fragments are made of Famennian (upper Devonian) siltstones. Some rounded pebbles were also observed in the deposit: these are quartzite pebbles coming from the river terrace overlying the valley side (Seret and de Béthune,1967).

The mean shape of the fraction >4 mm diameter (Krumbein, 1941) is 0·26 for the openwork material. For the matrix-rich sediment, the value is 0·24. This indicates a subangular shape, probably linked to movement downslope, e.g. locally concentrated flow, as suggested by Seret and de Béthune (1967).

The Index of Flattening (Cailleux and Tricart, 1963) has been calculated for the fraction >6 mm in diameter (Cailleux's method), its value being 5·44 for the openwork sediment and 6·02 for the matrix-supported material. This indicates that this material has to be considered as 'exceptionally fissile' (according to the terminology of Cailleux and Tricart), which is not surprising for such an easily weathered siltstone. The rock fragments are clearly elongated; their longest axis averages 16 mm long, with individual pebbles exceeding 30 mm in length.

Atterberg limits. The materials are non-plastic. The liquid limit is 21 per cent for the matrix-supported material and 30 per cent for the openwork sediment.

Pebble orientation. Figure 16 shows the rose diagrams for the stones in the two contrasting layers. It indicates that the rock fragments are very well oriented parallel to the slope direction in both cases. The remarkable elongation of the rock fragments probably helped a lot in determining this alignment.

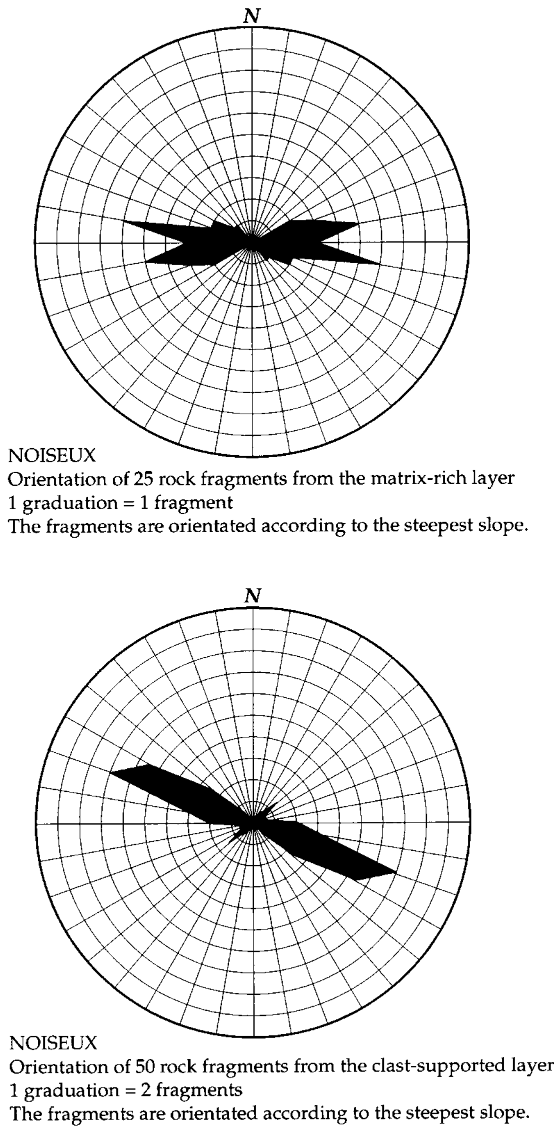


Figure 16. Rose diagrams for the stones in clast-supported and matrix-supported sediment, in the Noiseux deposit

COMPARISON OF THE STRATIFIED SLOPE DEPOSITS OF KLUANE AND FAMENNE

The parent materials in these two examples are different, yet the actual strata are very similar. In the case of Kluane, there is a single parent material that is being deposited on a very steep slope (34–45°), but in the case of the Famenne, shattered siltstone was mobilized with small amounts (5–10 per cent) of loess. In the Famenne, deposits with >33° bedding planes were recorded in the past, so that part of the original deposit was similar to that at Kluane. Today, the remaining material exhibits less steep bedding and appears to be from the run-out zone at the base of the slope.

The clast-supported material at both locations shows similar grain size and degree of sorting. In both cases, the shape indicates minor rounding during movement downslope. The clast orientation is more marked in the Famenne, perhaps because of remobilization or due to being deposited at the base of a linear outcrop. The

extreme elongation of the clasts would aid in the development of this orientation. At Kluane, the clasts are found on an arcuate fan which tends to produce greater variation in orientation.

In both cases, wetting of the material during wet weather would result in the mobilization of the matrix-supported material well before the clast-supported material started to flow. The differences in the actual values of liquid limit are probably due to the differences in the materials involved.

For these reasons, it appears that the processes involved in the formation of the two deposits are essentially the same, which suggests that the environment at Noiseux at the time the *éboulis stratifié* was formed was similar to that found today at Kluane Lake. In this case, each cyclothem on the steep (>33°) slope probably represents an annual layer, but this is unlikely to be true for the material on the more gentle slope from the base of the cliff that is studied here.

Comparing these results with past work, Macar and Alexandre (1958) attributed the formation of the matrix-supported layers to solifluction. This would assume alternating periods of several years of slow solifluction of the material alternating with periods of formation of the clast-supported layers. For the latter,Seret and de Béthune (1967)reported (qualitatively) rounding of the smallest particles of siltstone; from this they inferred that water action had removed the fines. However, only minor rounding was found in the present study, and there was no evidence to support washing away of fine particles. The snowmelt would have produced some water, as noted by Macar and Alexandre (1958), but the available evidence suggests it did not carry out any obvious geological work, any more than it does today at Kluane Lake.

Key factors in the formation of the stratified scree in the Yukon are a steep slope in suitably fractured rock and the alternating dry cold winter and spring conditions with much frost action followed by a wetter summer. They are forming in a region of discontinuous permafrost, though the latter is not directly involved in their formation. Presumably similar climatic conditions occurred at Noiseux during the formation of the *éboulis stratifié* there.

ACKNOWLEDGEMENTS

The field work in the Yukon was funded by NSERC Operating Grant No. A-7483. The work in Belgium has been partly supported by an FNRS Researcher Grant. The technical assistance of Mr J. L. Genicot at the University of Liège was made possible by the 'PRIME' project developed by the Minister of the Walloon Region, while Leona Piet, Denise Cook and Jennifer Waughtal received Northern Scientific Training Grants to help with the studies in the Yukon sections. Their help is also gratefully acknowledged.

REFERENCES

Alexandre, J. and Macar, P. 1960. Excursion du jeudi 11 juin 1959: Liège, Baraque de Fraiture, Laroche, Rochefort, Liège. Le périglaciaire préwürmien. Colloque international tenu à Liège du 9 au 12 juin 1959. Les Congrès et Colloques de l'Université de Liège, **17**, 187–197.

Bertran, P., Coutard, J. P., Francou, B., Ozouf, J. C. and Texier, J. P. 1992. Données nouvelles sur l'origine du litage des grèzes: implications climatiques. *Géographie Physique et Quaternaire,* **46**, 97–112.

Cailleux, A. and Tricart, J. 1963. Initiation à l'étude des sables et des galets, Tome 1: *Texte*. Centre de Documentation Universitaire: Paris.

Clague, J. J. 1979. The Denali Fault System in Southwest Yukon Territory–A geologic hazard? In *Current Research, Part A*. Geological Survey of Canada, Paper, **79-1A**, 169–178.

Corbel, J. 1954. Sols striés et éboulis ordonnés. *Revue de Géomorphologie Dynamique,* **1**, 31–33.

Delgado-Rodrigues, J. 1988. Proposed geotechnical classification of carbonate rocks on Portuguese and Algerian examples. *Engineering Geology,* **25**, 33–43.

Doeglas, D. J. 1946. Interpretation of the results of mechanical analyses. *Journal of Sedimentary Petrology,* **16**, 19–40.

Folk, R. 1980. Petrology of Sedimentary Rocks. Hamphill: Austin, Texas.

Francou, B. 1988. Eboulis stratifiés dans les Hautes Andes Centrales du Pérou. *Zeitschrift für Geomorphologie* N.F., **32**, 47–76.

Francou, B. 1990. Stratification mechanisms in slope deposits in high subequatorial mountains. *Permafrost and Periglacial Processes* **1**, 249–263.

French, H. M., Pissart, A. and Lewkowicz, A. 1995. Preface. *Permafrost and Periglacial Processes,* **6**, 2, ii.

Guillien, Y. 1951. Les grèzes litées de Charente. *Revue Géographique des Pyrénées et du Sud-Ouest,* **22**, 153–162.

Guillien, Y. 1964. Grèzes litées et bancs de neige. *Geologie en Mijnbouw,* **43**, 103–112.

Hamès, V, Lautridou, J. P., Ozer, A. and Pissart, A. 1987. Variations dilatométriques de roches soumises à des cycles "humidification-séchage". *Géographie Physique et Quaternaire,* **41**, 3, 345–354.

Harris, S. A. 1975. Petrology and origin of stratified scree in New Zealand. *Quaternary Research,* **5**, 199–214.

Harris, S. A. Gustafson CA. 1988. Retrogressive slumps, debris flows and river valley development in icy, unconsolidated sediments on hills and mountains. *Zeitschrift für Geomorphologie* N.F., **32**, 441–455.

Harris, S. A. and McDermid, G. 1998. Frequency of debris flows on the Sheep Mountain Fan, Kluane Lake, Yukon Territory. *Zeitschrift für Geomorphologie* N.F., **42**, 159–175.

Heine, K. 1995. Bedded slope deposits with respect to the Lake Quaternary glacial sequence in the High Andes of Ecuador and Bolivia. In Steepland Geomorphology, Slaymaker, O. (ed.). John Wiley: New York; 259–278.

Hétu, B., van Steijn, H. and Bertran, P. 1995. Le rôle des coulées de pierres sèches dans la génèse d'un certain type d'éboulis stratifié. *Permafrost and Periglacial Processes,* **6**, 173–194.

Journaux, A. 1976. Les grèzes litées du Châtillonais. *Bulletin Association Française Elude du Quaternaire,* **3–4**, 123–138.

Juvigné, E. 1963. La région du coude de l'Ourthe à Noiseux: Etuide de géomorphologie. Contribution à l'élaboration de la carte géomorphologique de la Belgique. BSc thesis, University of Liège.

Kay, M. and Colbert, E. H. 1965. Stratigraphy and Life History. J. Wiley: New York.

Krumbein, W. C. 1941. Measurement and geological significance of shape and roundness of sedimentary particles. *Journal of Sedimentary Petrology,* **11**, 164–172.

Lliboutry, L. 1961. Phénomènes cryonivaux dans les Andes de Santiago. *Builetyn Peryglacjalny,* **10**, 209–224.

Macar, P. and Alexandre, A. 1958. Compte-rendu de la session extraordinaire de la Socieété Géologique de Belgique et de la Société Belge de Géologie tenue à Liège, Trois-Ponts et La Roche du 20 au 23 septembre, 1957. *Annales de la Société Géologique de Belgique,* **81**, 1–107.

Malaurie, J. 1949. Evolution actuelle des pentes sur la côte ouest du Groenland (Baie de Disko). *Bulletin de l'Association des Géographes Français',* **1**, 1–8.

Pissart, A. 1976. Les dépôts et la géomorphologie périglaciaire de la Belgique. In Géomorphologie de la Belgique: Hommage au Professeur Macar, Pissart A (ed). Labaratoire de Géographie Physique, Universite de Liège; 115–135.

Pissart, A. 1995. L'Ardenne sous le joug du froid: le modelé périglaciaire du Massif Ardennais. In L'Ardenne, Essai de Géographie Physique: Hommage au Professeur Pissart, Demoulin A (ed.). Département de Géographie Physique et Quaternaire, Université de Liège; 136–154.

Seret, G. 1963. Essai de classification des pentes en Famenne. *Zeitschrift für Geomorphologie,* **7**, 71–85.

Seret, G. and de Béthune, P. 1967. Compte rendu de l'excursion du semedi 11 juin 1966. La Rocheen-Ardenne, Marche, Han-sur-Lesse, Namur. In L'évolution des versants, Macar P (ed.). International Geomorphology Symposium, Liège-Louvain, 8–16 June 1966. Le rapport de la commission pour l'étude de l'évolution des versants de l'Union Géographique Internationale: Liège; 325–348.

Tricart, J. and Cailleux, A. 1967. Traité de Géomorphologie: le modelé des régions périglaciaires. Paris.

van Steijn, H., Van Brederode, L. and Goedheer, J. G. 1984. Stratified slope deposits of the grèze litée type in the Ardèche region in the south of France. *Geografiska Annaler,* **66A**, 295–305.

van Steijn, H., Bertran, P., Francou, B., Hétu, B. and Texier, J. P. 1995. Models for the genetic and environmental interpretation of stratified slope deposits: review. *Permafrost and Periglacial Processes,* **6**, 125–146.

Wasson, R. J. 1979. Stratified slope deposits in the Hindu Kush, Pakistan. *Zeitschrift für Geomorphologie,* **23**, 301–320.

Wheeler, J. O. 1963. *Kaskawulsh–Geology*. Geological Survey of Canada, Map 1134A.

